OFFICE OF NAVAL RESEARCH
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A. Summary of Research

The aim of the research supported by the ONR contract has been to improve our understanding of factors leading to solar flares, with the long-term goal of improving predictions of these events.

To achieve this goal, we have studied spatial and temporal patterns in solar flare occurrences. We have found that solar flares tend to occur in "hot spots," which rotate rigidly (Bai 1990). The two northern-hemisphere hot spots, which rotate with a synodic period of 26.727 days (24.905 days in sidereal), persisted in the same locations during cycles 20 through 22. We have made extensive studies on quasi-periodic changes of flare occurrence rates. Occurrence rates of major flares, regardless of selection criteria, episodically show periodic variations. The well-known period is 154 days (Rieger et al. 1984; Bai and Cliver 1990, and references therein). In addition to this, periodicities of 51, 77, 103, and 129 days have been detected (Bai and Sturrock 1991; Bai 1992a, 1992b, 1993b).

Because all these periods are close to integral multiples of 25.5 days, we have proposed that 25.5 days is the fundamental period with other periods being its subharmonics. We have searched the "clock mechanism" for the fundamental period. On the basis of analysis of flare distributions for the 36-year data (1955-1991), we proposed that a rotation of a structure with a period of 25.50 days might be the clock mechanism (Bai and Sturrock 1993). The rotation axis seems to be tilted by 40 degrees with respect to the ecliptic normal, and the direction of the tilt is toward the earth's position on December 4 on its revolutionary orbit.

Solar flares may derive their energies from magnetic "free energy" that is stored in the coronal magnetic field. This free energy is associated with electric currents that are present whenever the field is stressed. Using the magneto-frictional method, we have studied various force-free-field configurations that may arise on the Sun (Klimchuk 1990; Porter et al. 1992). We have extended the magneto-frictional method to 3-D cases

(Klimchuk and Sturrock 1992). To apply the method to realistic cases, a 3-D extension is essential.

In addition to the above mentioned areas, we have performed research in coronal heating (Sturrock et al. 1990). This is not only one of the unsolved problems in solar physics but has relevance to the understanding of solar activity because the corona provides the environmental conditions for solar flare occurrence. Our research effort includes studies on other aspects of solar flares not mentioned above (Sturrock 1991; Bai 1993a) and plasma physical processes related to solar activity (Sturrock 1990; Antiochos and Klimchuk 1991; Klimchuk et al. 1992; Sturrock 1991). The enclosed list of publications shows our research activity in more detail.

References

Antiochos, S. K., and Klimchuk, J. A. 1991, Ap. J., 378, 372

Bai, T. 1990, Ap. J. (Letters), 364, L17

Bai, T. 1992a, Ap. J. Letters, 388, L69

Bai, T. 1992b, Ap. J. 397, 584

Bai, T. 1993a, Ap. J. 404, 805

Bai, T. 1993b, Solar Phys. (submitted)

Bai, T. & Cliver, E. W. 1990, Ap. J., 363, 299

Bai, T., & Sturrock, P.A. 1991, Nature 350, 141

Bai, T., & Sturrock, P.A. 1993, Ap. J. 409, 476

Klimchuk, J. A. 1990, Ap. J., 354, 745-754

Klimchuk, J. A., Canfield, R. C., and Rhoads, J. E. 1992, Ap. J., 385, 327

Klimchuk, J. A., and Sturrock, P. A. 1992, Ap. J., 385, 344

Porter, L. J., Klimchuk, J. A., and Sturrock, P. A. 1992, Ap. J., 385, 738

Sturrock, P.A. 1990, Ap.J., 380, 655

Sturrock, P.A. 1991, Comments in Astrophysics, 16, 71

Sturock, P.A., Dixon, W.W., Klimchuk, J.A., and Antiochos, S.K. 1990, Ap. J. (Letters), 356, L3

List of Publications Supported by
the ONR Contract N00014-91-J-1112

Bai, T. 1990, Ap. J. (Letters), 364, L17
Solar 'Hot Spots' are Still Hot

Bai, T. & Cliver, E. W. 1990, Ap. J., 363, 299
A 154-Day Periodicity in the Occurrence Rate of Proton Flares

Bai, T., Cliver, E.W., & Kile, J. N. 1990, Proc. 21st Intern. Cosmic Ray Conf. (Adelaide), 5, 20
A 154-Day Periodicity in the Occurrence Rate of Flares for Solar Cycle 19 through 21

Klimchuk, J. A. 1990, Ap. J., 354, 745-754
Shear-Induced Inflation of Coronal Magnetic Fields

Sturock, P.A., Dixon, W.W., Klimchuk, J.A., and Antiochos, S.K. 1990, Ap. J. (Letters), 356, L31-L34
Episodic Coronal Heating

Sturrock, P.A. 1990, Ap.J., 380, 655-659
Maximum energy of semi-infinite magnetic field configurations

Sturrock, P.A., Dixon, W.W., Klimchuk, J.A., and Antiochos, S.K. 1990, Ap. J. (Letters), 356, L31-L34
Episodic Coronal Heating

Antiochos, S. K., and Klimchuk, J. A. 1991, Ap. J., 378, 372-377
A New Model For the Formation of Solar Prominences

Bai, T., Sturrock, P.A., 1991, Nature 350, 141-143
The 154-Day and Related Periodicities of Solar Activity as Subharmonics of a Fundamental Period

Klimchuk, J. A, Canfield, R. C., and Rhoads, J. E. 1991, Flare Physics in Solar Activity Maximum 22, (eds. Y. Uchida, R. C. Canfield, T. Watanabe, E. Hiei; Berlin: Springer-Verlag), p. 219-223
The Practical Application of the Magnetic Virial Theorem

Sturrock, P.A. 1991, Comments in Astrophysics, 16, 71 - 85
The Emerging Picture of Eruptive Solar Flares

Sturrock, P.A. 1991, Lecture Notes in Physics 387, Flare Physics in Solar Activity Maximum 22 (eds. Y. Uchida, R.C. Canfield, T. Watanabe and E. Hiei; Berlin, Springer), pp. 224-227
Maximum Energy of Semi-Infinite Magnetic Field Configurations.

Bai, T. 1992, Ap. J. Letters, 388, L69

The 77-day periodicity in the Flare Occurrence Rate of Cycle 22

Bai, T. 1992, Ap. J. 397, 584
Methods of Periodicity Analysis: Relationship between the Rayleigh Analysis and a Maximum Likelihood Method

Klimchuk, J. A., and Sturrock, P. A. 1992, Ap. J., 385, 344-353
Three-Dimensional Force-Free Magnetic Fields and Flare Energy Buildup

Klimchuk, J. A., Canfield, R. C., and Rhoads, J. E. 1992, Ap. J., 385, 327
The Practical Application of the Magnetic Virial Theorem

Porter, L. J., Klimchuk, J. A., and Sturrock, P. A. 1992, Ap. J., 385, 738-745
Cylindrically Symmetric Force-Free Magnetic Fields

Sturrock, P.A. 1992, Proc. IAU Coll. 133 (Iguazu, August 1991) on Eruptive Solar Flares (Springer-Verlag, 1992), 397 - 409
The Emerging Picture of Eruptive Solar Flares

Sturrock, P.A., and Bai, T. 1992, Ap. J., 397, 337 - 346
Search for Evidence of a Clock related to the Solar 154-day Complex of Periodicities

Bai, T. 1993, Ap. J. 404, 805
Variability of the Occurrence Frequency as a Function of Hard X-Ray Peak Rate

Bai, T., and Sturrock, P.A. 1993, Ap. J. 409, 476 - 486
Evidence for a fundamental period of the Sun and its relation to the 154-day complex of periodicities

Bai, T. 1993, Solar Phys. (submitted)
The Appearance of the 51-day Periodicity in Cycle 22